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Soil Carbon, Nitrogen, and Aggregation in Response to Type and Frequency of Tillage

A. J. Franzluebbers,* G. W. Langdale, H. H. Schomberg

ABSTRACT

Little information exists on the biogeochemical effects of combining no-tillage planting with paraplowing (to improve deep water penetration) or with secondary tillage (to control weeds). We determined surface residue and soil C and N pools (total, particulate, microbial biomass, and mineralizable) and water-stable aggregation at depths of 0 to 25, 25 to 75, and 75 to 150 mm from a Cecil sandy loam (fine, kaolinitic, thermic Typic Kanhapludults) in Georgia. Soil tillage treatments were a factorial arrangement of tillage type [(i) minimal disturbance with in-row chisel at planting, (ii) no-tillage planting with autumn paraplow, and (iii) no-tillage planting with secondary tillage during the summer] and tillage frequency [(i) every year, (ii) every second year, and (iii) every fourth year]. No-tillage planting without further disturbance occurred in remaining years. At a depth of 0 to 25 mm, basal soil respiration averaged 9 mg kg^{-1} d^{-1} with conventional tillage, 27 mg kg^{-1} d^{-1} with no-tillage planting and soil disturbance every year, and 36 mg kg^{-1} d^{-1} with no-tillage planting and soil disturbance every fourth year. At a depth of 0 to 150 mm, mean-weight diameter averaged 1.03 mm with conventional tillage, 1.12 mm with paraplow, 1.17 mm with secondary tillage, and 1.23 mm with in-row chisel. No-tillage planting with alternative tillage types and frequencies not only improved surface soil properties compared with conventional tillage, but also improved seed cotton yield an average of 19%. Biophysical improvement of surface soil structure would presumably lead to greater water infiltration and improved water use efficiency in the long term.

SOILS OF THE AMERICAN SOUTHERN PIEDMONT have undergone severe erosion and degradation as a result of intensive tillage (Langdale et al., 1994). Conservation tillage improves soil chemical, physical, and biological properties of previously cultivated soils in many parts of the world (Doran, 1980; Paul et al., 1997), particularly in the southeastern USA (Beare et al., 1994; Bruce et al., 1995). Although much has been learned about the changes in soil quality with the conversion of previously tilled cropland to untilled cropland, relatively little is known about the potential changes in soil quality when combining no-tillage planting with paraplowing (PP) to improve deep water percolation, or with secondary tillage (ST) to control weeds. These alternative tillage practices may be important in some situations to reduce producers' risks of crop failure by alleviating environmental limitations (e.g., improving deep penetration of water into dense subsoils, controlling opportunistic weeds, or obtaining good seed establishment), especially during the transition from conventional tillage (CT) to conservation tillage.

Improving effective utilization of rainfall in the southeastern USA is of major importance in sustaining agricultural productivity and providing enough plant-derived C to maintain or improve soil quality. Long-term no-tillage crop production can greatly reduce erosion and improve water-use efficiency in the Southeast (Langdale and Moldenhauer, 1995). However, immediate benefits during the transition from conventional to conservation tillage are not always realized because of water and weed problems. Investigation by Clark et al. (1993) indicated that yearly paraplowing decreased penetration resistance and increased water infiltration, but did not affect sorghum [*Sorghum bicolor* (L.) Moench] yield compared with less frequent paraplowing. Some producers have been reluctant to adopt no tillage because of concerns about effective weed control and use of more pesticides that might threaten environmental quality if leached or lost via runoff. Our objective was to quantify the effects of (i) type of tillage that alternated with no-tillage planting and (ii) frequency of the alternative tillage component on soil properties thought to be important in assessing soil quality of crop production systems.

MATERIALS AND METHODS

A field experiment was initiated in the autumn of 1991 on a Cecil sandy loam near Watkinsville, GA (33°59′ N, 83°27′ W). Clay content averaged 129 g kg^{-1} and sand content averaged 668 g kg^{-1} at a depth of 0 to 150 mm. Mean annual temperature is 16.5°C, mean annual precipitation is 1250 mm, and mean annual evaporation is 1560 mm, although typically with moisture excess from November through March. The site was fallowed by mowing volunteer plant growth for four years immediately prior to this experiment and was cropped with sorghum and soybean [*Glycine max* (L.) Merr.] for eight years prior to the fallow period. Crimson clover (*Trifolium incarnatum* L.) was grown as a winter cover crop and millet (*Panicum miliaceum* L.) was grown in the summer during 1992 and 1993. During 1994 to 1996, cotton (*Gossypium hirsutum* L.) with a rye (*Secale cereale* L.) cover crop was grown. Cover crops were sown in October or November. All summer crops except those with in-row chisel treatment (IC) were no-tillage planted into herbicide-killed cover crops in 0.76-m-wide rows in May or June. Alternative tillage operations combined with no-tillage planting were IC at planting (≈250-mm depth) to provide a loosened soil zone below the seed, PP in autumn (≈400-mm

USDA-ARS, J. Phil Campbell Sr. Natural Resources Conservation Center, 1420 Experiment Station Rd., Watkinsville, GA 30677-2373. Received 23 March 1998. *Corresponding author (afranz@arches.uga.edu).

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Abbreviations: CT, conventional chisel and disk tillage; IC, in-row chisel; PP, paraplow; ST, secondary tillage.

depth) following harvest of the summer crop to improve deep water percolation, and ST with a wide sweep (≈50-mm depth) two to three times during the summer growing season to control weeds. The alternative tillage operations were performed for the summer crop in 1992 (sampled 4 yr since tillage), for the summer crops in 1992 and 1994 (sampled 2 yr since tillage), and for the summer crops in 1992, 1993, 1994, and 1995 (sampled 1 yr since tillage). In-row chisel at planting and conventional disk tillage (100–150 mm depth) in autumn and spring to incorporate residue each year without cover crop was included as a control. The 10 treatments were randomized within three blocks. Plots measured 6 m wide and 30 m long.

Soil was sampled during the first week of June 1996 as cotton was emerging and after rye was sprayed with paraquat (1,1′-dimethyl-4,4′-dipyridinium ion) in May. Five locations from a fixed, diagonal pattern were separated by 2 m parallel to rows and 0.2 m perpendicular to rows within each plot; each was sampled and composited. Surface residue was collected from within a 123-mm-radius ring. Soil cores (41-mm diam) were collected following surface residue removal at depths of 0 to 25, 25 to 75, and 75 to 150 mm. Soil and residue were dried at 55°C for 48 h. Soil for all analyses was gently crushed to pass a 4.75-mm screen and stones removed. Soil bulk density was determined from the weight of soil prior to screening and the volume of the coring device. Subsamples of soil (ground in a ball mill for 5 min) and residue (ground to <1 mm) were analyzed for total C and N using dry combustion. It was assumed that total soil C was equivalent to soil organic C, because soil pH was near 6.2.

Carbon mineralization was determined by placing two 60-g soil subsamples (30 g per subsample for the 0–25 mm depth) that were packed to 1.33 Mg m^{-3} (1.2 Mg m^{-3} for the 0–25 mm depth) in 60-mL glass jars, wetting the subsamples to 50% water-filled pore space and placing them in 1-L canning jars along with 10 mL of 1 *M* NaOH to trap CO_2 and a vial of water to maintain humidity. Samples were incubated at 25 ± 1°C for 24 d. Alkali traps were replaced at 3 and 10 d of incubation, and CO_2–C was determined by titration with 1 *M* HCl in the presence of excess $BaCl_2$ to a phenolphthalein endpoint. Basal soil respiration was calculated as the linear rate of C mineralization between 10 and 24 d. At 10 d, one of the subsamples was removed from the incubation jar, fumigated with $CHCl_3$ under vacuum, and vapors removed at 24 h. It was then placed into a separate canning jar along with vials of alkali and water and incubated at 25°C for 10 d. Soil microbial biomass C was calculated as the quantity of CO_2–C evolved following fumigation divided by an efficiency factor of 0.41 (Franzluebbers et al., 1996). Potential N mineralization was determined from the difference in inorganic N concentration between 0 and 24 d of incubation. Inorganic N (NH_4–N + NO_2–N + NO_3–N) was determined from the filtered extract of a 10-g subsample of dried (55°C for 48 h) and sieved (<2 mm) soil that was shaken with 20 mL of 2 *M* KCl for 30 min using autoanalyzer techniques (Bundy and Meisinger, 1994).

Particulate organic C and N were collected from a 60-g subsample (30 g for the 0–25 mm depth) that was shaken with 100 mL of 0.1 *M* $Na_4P_2O_7$ for 1 h on a reciprocating shaker, allowed to settle in dispersing solution for 16 h, shaken again for 1 h, diluted to 1 L with distilled water, allowed to settle for 5 h, and then passed through a 0.05-mm screen. Sand and organic material not passing the screen were dried at 55°C for 72 h, ground in a ball mill for 5 min and analyzed for total C and N using dry combustion.

Water-stable aggregation was determined using a wet-sieving procedure. A 60- to 80-g sample was placed on a nest of sieves (175-mm diam) with openings of 1.0 and 0.25 mm, immersed in water, and oscillated for 10 min (20-mm stroke length, 31 cycles min^{-1}). Floating organic material retained within the walls of the top screen was removed by suction, collected on a screen, and dried in a bottle. After removing the two sieves and placing them in an oven, water containing soil that passed the 0.25-mm screen was poured over a 0.05-mm screen and the soil retained was transferred into a drying bottle with a small stream of water. The <0.05-mm fraction was calculated as the difference between initial soil weight and summation of the 1.0 to 4.75, 0.25 to 1.0, and 0.05 to 0.25 mm fractions. All fractions were oven-dried at 55°C for ≥24 h following visual dryness. Mean-weight diameter of soil was calculated by summing the products of water-stable aggregation fraction and mean diameter of water-stable aggregation class, excluding the floating material.

Soil properties were analyzed for variance due to replication (2 df) and tillage type × frequency combinations (9 df) using the general linear model procedure of SAS (SAS Institute, 1990). Orthogonal contrast statements were used to separate individual components of the tillage type × frequency combinations. Effects were considered significant at $P \leq 0.1$.

Table 1. Standing stock of soil organic C pools to a depth of 150 mm as affected by tillage type and frequency.

Tillage system		Carbon pool‡					
Type†	Years since tillage	BSR	SMBC	POC	SOC	Residue C	Total C
		g m^{-2} d^{-1}	g m^{-2}				
CT	0	1.50	119	506	2109	11	2121
IC	1	2.17	144	756	2134	253	2386
IC	2	2.23	143	650	2087	310	2397
IC	4	2.05	148	725	2135	244	2379
PP	1	1.87	136	578	2060	215	2275
PP	2	2.22	148	578	2062	287	2348
PP	4	2.27	141	654	2222	428	2650
ST	1	1.88	129	574	1849	294	2143
ST	2	2.29	140	659	1934	262	2196
ST	4	2.60	147	644	2160	265	2425
LSD ($P < 0.01$)		0.41	18	115	432	79	458

† CT is conventional chisel and disk tillage, IC is in-row chisel, PP is paraplow, and ST is secondary tillage.
‡ BSR is basal soil respiration, SMBC is soil microbial biomass carbon, POC is particulate organic carbon, SOC is soil organic carbon, and total C is the sum of SOC and residue C.

RESULTS AND DISCUSSION

Surface Residue

Residue C content increased with time since tillage from 254 ± 40 g m^{-2} at one year to 286 ± 24 g m^{-2} at two years, and to 312 ± 101 g m^{-2} at four years since the last tillage operation (mean ± standard deviation among alternative tillage types) (Table 1). Less soil disruption resulted in greater accumulation of surface residue C. Any minor mixing of residue with soil would allow residue to remain wetter and, therefore, provide more ideal conditions for microbial decomposition that leads to surface residue loss.

Surface residue mass was 0.79 ± 0.17 kg m^{-2} among alternative tillage systems with a cover crop, but only 0.04 kg m^{-2} in CT without a cover crop. From all treatments, residue C and N concentrations were 365 ± 37 g C kg^{-1} and 10.4 ± 2.0 g N kg^{-1}, respectively. Residue C to N ratio decreased from 40 at one year to 36 at two years, and to 33 at four years since the last tillage operation. This decreasing C to N ratio of surface resi-

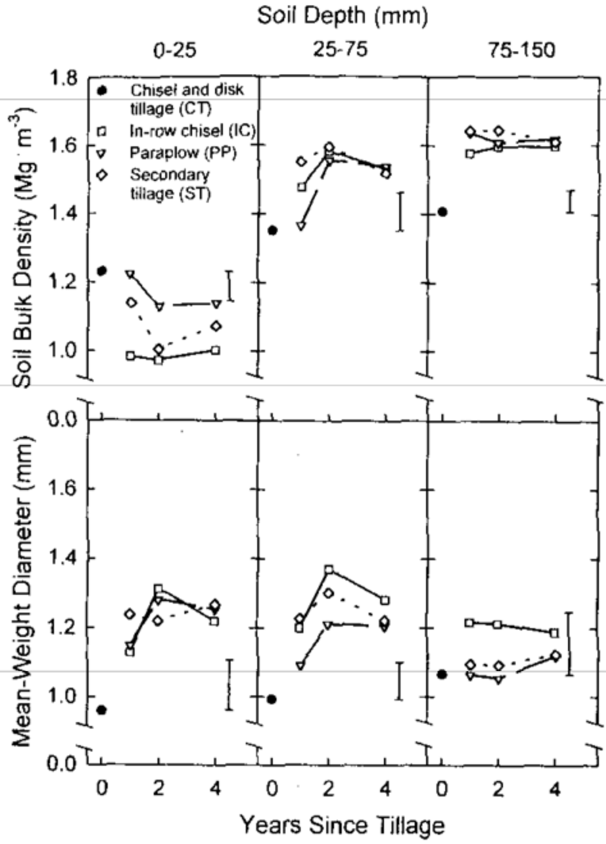

Fig. 1. Soil bulk density and mean-weight diameter of water-stable aggregates as affected by soil depth, tillage type, and tillage frequency (1, 2, and 4 years since tillage were tilled 4, 2, and 1 years in four years, respectively). Error bars are LSD ($P \leq 0.1$).

due suggests that more residue with intermediate decomposition (i.e., with lower C to N ratio) diluted the pool of residue with less frequent tillage. Although we did not separate the contribution of currently produced residue from that of previous years, net residue accumulation with no-tillage planting and various alternative tillage types and frequencies was relatively low compared with annual residue production estimates. No-tillage sorghum and soybean systems with cover crop in the Georgia Piedmont typically produce 0.8 to 1.2 kg stover m^{-2} yr^{-1} (Bruce and Langdale, 1997), which is approximately 300 to 500 g C m^{-2} yr^{-1}. However, cotton residue production is usually substantially less than grain residue production systems. Surface residue accumulation in this study was at or below these annual estimates of stover production, suggesting that crop residue decomposition, even under minimum disturbance, was very fast in this warm, moist climate. Under similar environmental conditions of the Georgia Piedmont, 35 and 50% of the N from a crimson clover cover crop was released during the first four and eight weeks, respectively, under no tillage (Wilson and Hargrove, 1986).

Soil Bulk Density

Soil bulk density with alternative tillage was generally lower in comparison with CT at a depth of 0 to 25 mm, but greater at depths of 25 to 75 and 75 to 150 mm (Fig. 1). Averaged across tillage frequencies, soil bulk density to a depth of 150 mm was 1.36 Mg m^{-3} under CT, 1.47 Mg m^{-3} under IC, 1.50 Mg m^{-3} under PP, and 1.51 under ST. Differences in bulk density among tillage types to a depth of 150 mm were mainly due to differences at a depth of 0 to 25 mm. Bulk density at a depth of 0 to 25 mm averaged 0.99 Mg m^{-3} under IC, 1.07 Mg m^{-3} under ST, and 1.17 Mg m^{-3} under PP.

Bulk density at depths of 0 to 25 and 25 to 75 mm with the most frequent PP (one year since last tillage) was more similar to CT than with less frequent PP. Other alternative tillage operations did not exhibit this temporal dependence in bulk density, perhaps due to their less disruptive effects on soil. Reconsolidation of soil following PP appeared to be near completion within two years of tillage, since changes in bulk density occurred between one and two years, but not between two and four years since last PP. This temporal dependence upon an infrequent deep tillage event was also observed on a somewhat poorly drained loam soil in Michigan where moldboard plowing was alternated with no tillage (Pierce et al., 1994).

Water-Stable Aggregation

Mean-weight diameter of water-stable aggregates was greater under all alternative tillage types and frequencies than under CT at a depth of 0 to 25 mm (Fig. 1). No differences in mean-weight diameter were observed due to type or frequency of alternative tillage at this depth. These data indicate that cover cropping alone, rather than reduced soil disturbance, may have improved aggregation since mean-weight diameter was little affected by type and frequency of alternative tillage.

The fraction of soil in water-stable aggregate classes of 1 to 4.75, 0.25 to 1, 0.05 to 0.25, and <0.05 mm under CT was 0.22, 0.47, 0.24, and 0.07, respectively, and under alternative tillage systems was 0.31 ± 0.03, 0.48 ± 0.01, 0.15 ± 0.02, and 0.07 ± 0.01, respectively (mean ± standard deviation among tillage types and frequencies). Bruce and Langdale (1997) reported an improvement in water-stable aggregation of surface soil at the end of five years under no tillage and cover cropping, as well as a 40 to 50% increase in water infiltration compared with conventional tillage and summer copping on a similar soil. Resistance of soil to disruption by intense storms, which are common during the summer in the southeastern USA (Barnett and Hendrickson, 1960), would help improve crop water-use efficiency by reducing slaking, which seals soil pores and causes water runoff.

At a depth of 25 to 75 mm, tillage frequency had no effect on mean-weight diameter (Fig. 1). Averaged across tillage frequencies, mean-weight diameter was greater under IC and ST than under PP at this depth.

At a depth of 75 to 150 mm, mean-weight diameter was greater under IC than under PP and ST when averaged across tillage frequencies. Mean-weight diameter values under PP and ST were similar to that under CT, but the difference between IC and CT was still significant at 75 to 150 mm. It appears that the timing or direction of soil disturbance with IC led to deeper

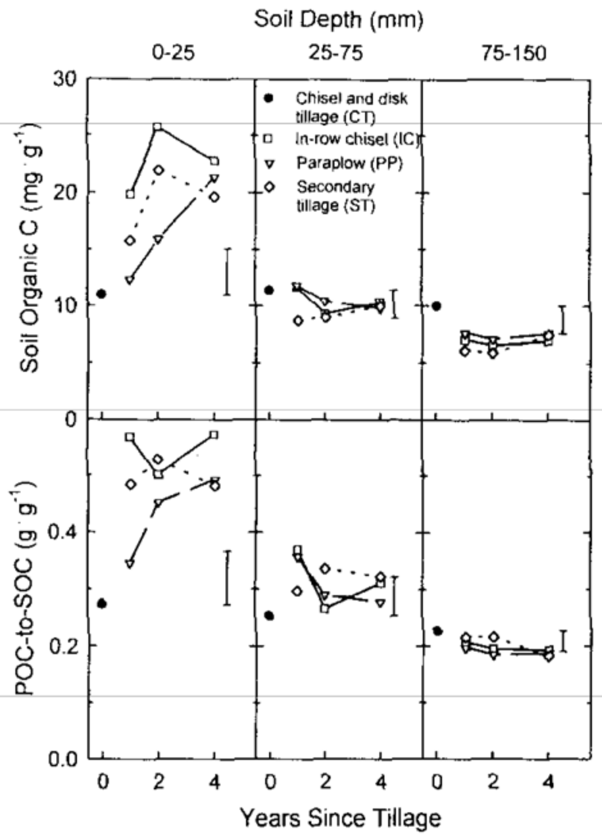

Fig. 2. Soil organic C and the ratio of particulate organic C to soil organic C (POC to SOC) as affected by soil depth, tillage type, and tillage frequency (1, 2, and 4 years since tillage were tilled 4, 2, and 1 years in four years, respectively). Error bars are LSD ($P \leq 0.01$).

effects on mean-weight diameter than the deeper and vertically disruptive PP and the shallower, but horizontally disruptive ST. It should be noted that the higher mean-weight diameter under alternative tillage systems than that under CT may have been due to the cover crop, which may have provided C inputs from roots that improved aggregation. However, the difference in vertical distribution of mean-weight diameter between alternative tillage systems and CT followed a pattern similar to the difference between no tillage and shallow cultivation in loam and sandy loam soils in Canada (Franzluebbers and Arshad, 1996b).

Soil Organic Carbon and Nitrogen

Soil organic C at a depth of 0 to 25 mm was greater under all alternative tillage types and frequencies than under CT, except annual PP (Fig. 2). Averaged across tillage frequencies, soil organic C was greater under IC than under PP and ST and greater under ST than under PP at this depth. With increasing alternative tillage frequency, soil organic C decreased in all tillage systems, but decreased more dramatically with PP than with ST or IC. Soil organic N followed the same patterns as soil organic C, resulting in a C to N ratio of 13.5 ± 0.2 among all tillage types and frequencies.

At a depth of 25 to 75 mm, soil organic C was unaffected by tillage type and frequency (Fig. 2). However at a depth of 75 to 150 mm, soil organic C was 31 ± 6% lower and soil organic N was 33 ± 7% lower under alternative tillage types and frequencies than under CT. No tillage planting with cover cropping and infrequent alternative tillage resulted in a redistribution of soil organic C, with more soil organic C near the surface and less with depth in comparison with CT and no cover crop. This result is similar to those of many studies investigating the effect of conservation tillage in comparison with more conventional deep tillage (Doran, 1980; Ismail et al., 1994; Franzluebbers et al., 1995).

To a depth of 150 mm, soil organic C was not different among tillage types and frequencies (Table 1). No change in soil organic C due to reduction in tillage on this same soil was also reported by Langdale et al. (1990) and may be partly due to (i) redistribution within the soil profile, such that only the surface 10 to 20 mm may accumulate soil organic C with tillage reduction (Bruce et al., 1995); or (ii) insufficient length of time for differences to have become significant (Hendrix, 1997).

Addition of residue C to the standing stock of soil organic C did not result in a significant change in total C among tillage types and frequencies. The fraction of total C (residue plus soil C to a depth of 150 mm) as residue C was 0.12 ± 0.02 (mean ± standard deviation among alternative tillage types and frequencies) (Table 1). Redistribution without significantly altering standing stock of soil organic C with reduction in tillage intensity has been observed in other studies (Carter and Rennie, 1982; Franzluebbers and Arshad, 1996a; Angers et al., 1997). The difference in total C between alternative tillage types and CT at the end of 4 yr, although not significant, was 0.23 ± 0.15 kg m^{-2}. This difference to a depth of 150 mm is comparable to the difference between no tillage and plowing at the end of 6 yr in Minnesota (0.16 kg m^{-2}) and at the end of 12 and 13 yr in Nebraska (0.19 to 0.33 kg m^{-2}) (Doran, 1987), but smaller than that found at the end of 13 yr in Georgia (0.46 kg m^{-2}) (Beare et al., 1994) and at the end of 20 yr in Kentucky (0.84 kg m^{-2}) (Ismail et al., 1994). To a depth of 200 mm, the difference between no tillage and shallow, conventional tillage was found to be 0.01 kg m^{-2} at the end of 16 yr in south Texas (Salinas-Garcia et al., 1997), 0.15 ± 0.45 kg m^{-2} at the end of 4 to 16 yr in Alberta and British Columbia (Franzluebbers and Arshad, 1996b), and 0.42 ± 0.33 kg m^{-2} at the end of 9 yr in southcentral Texas (Franzluebbers et al., 1994, 1995).

Particulate Organic Carbon and Nitrogen

To a depth of 150 mm, particulate organic C was greater under alternative tillage systems compared with CT and greater under IC than under PP and ST when averaged across tillage frequencies (Table 1). Generally, particulate organic C and N followed similar patterns with respect to tillage type and frequency at all depths as soil organic C and N. However when averaged across tillage frequencies, the ratio of particulate organic C to soil organic C at a depth of 0 to 25 mm was greater under IC than under PP and ST and greater under ST than under PP (Fig. 2). The particulate organic C to soil organic C ratio decreased more dramatically with increasing PP frequency compared with increasing ST or IC frequency. This difference may be due to residues falling into large, vertical cracks that develop with PP. No differences in this ratio were observed among alternative tillage types and frequencies at depths of 25 to 75 mm and 75 to 150 mm.

Particulate organic C and N provide estimates of the intermediate pool of organic matter between the active and passive pools (Cambardella and Elliott, 1992). The particulate pool is composed primarily of partially decomposed roots and residues. The higher ratio of particulate organic C to soil organic C at the soil surface and lower ratio at a depth of 75 to 150 mm under alternative tillage systems compared with CT is not only a direct indication of residue placement under these different residue management systems, but also an index of the susceptibility to decomposition of recent root and residue inputs as affected by intensity of soil mixing or disturbance. Significant changes in the ratio of particulate organic C to soil organic C due to tillage type and frequency suggest that particulate organic C may be a more sensitive soil property than soil organic C to assess short-term changes in soil quality due to tillage management.

Soil Microbial Biomass and Activity

Soil microbial biomass C at a depth of 0 to 25 mm was greater under alternative tillage systems compared with CT (Fig. 3). Averaged across tillage frequencies, soil microbial biomass C was greater under IC than under PP and ST at the soil surface. At a depth of 25 to 75 mm, soil microbial biomass C increased more with increasing PP frequency compared with increasing ST frequency. This difference was similar to that observed for particulate organic C (data not shown) and may be due to the direct relationship of particulate organic C providing substrate for the growth of soil microbial biomass.

At a depth of 75 to 150 mm, soil microbial biomass C was lower under alternative tillage systems than under CT, but not different among alternative tillage types and frequencies (Fig. 3). As a standing stock to a depth of 150 mm, soil microbial biomass C was greater under alternative tillage systems than under CT (Table 1). Soil microbial biomass C was redistributed within the soil profile in a pattern similar to that observed for soil organic C and particulate organic C.

Generally, basal soil respiration responded to alternative tillage types and frequencies at different depths similarly to that observed for soil microbial biomass C (data not shown). However, the ratio of basal soil respiration to soil microbial biomass C (commonly referred to as the specific respiratory activity) was greater under ST than under PP when averaged across tillage frequencies at a depth of 0 to 25 mm (Fig. 3). This ratio also decreased with increasing PP and ST frequency at a depth of 0 to 25 mm. At a depth of 25 to 75 mm, the ratio tended to increase with increasing PP frequency,

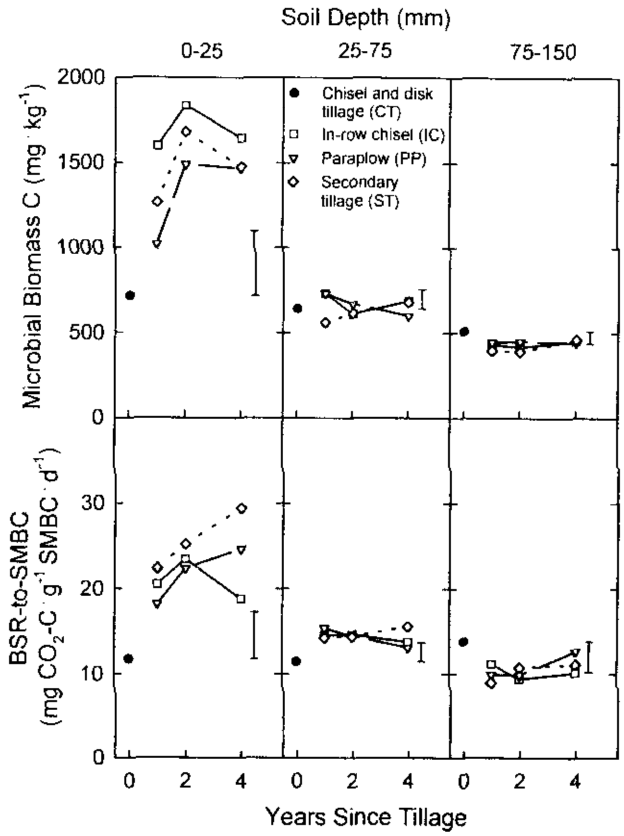

Fig. 3. Soil microbial biomass C and the ratio of basal soil respiration to soil microbial biomass C (BSR to SMBC) as affected by soil depth, tillage type, and tillage frequency (1, 2, and 4 years since tillage were tilled 4, 2, and 1 years in four years, respectively). Error bars are LSD ($P \leq 0.01$).

similar to the effects on particulate organic C and soil microbial biomass C. High ratios of basal soil respiration to soil microbial biomass C are indicative of the presence of readily mineralizable C that has not yet led to growth of the microflora under perturbations that usually result from physical disruption, osmotic shock, metal toxicity, or large organic amendments. Differences in the ratio of basal soil respiration to soil microbial biomass C in this study were likely caused by physical disruption due to tillage operations and root and residue placement differences.

As a standing stock to a depth of 150 mm, basal soil respiration was greater under alternative tillage systems than under CT (Table 1). Further, basal soil respiration decreased with increasing PP and ST tillage frequency, but not with IC frequency. It seems that PP and ST were more disruptive than IC, resulting in loss of mineralizable substrates due to decomposition in the field.

Potential Nitrogen Mineralization

Potential N mineralization at a depth of 0 to 25 mm was greater under alternative tillage systems than under CT (Fig. 4). Averaged across tillage frequencies, potential N mineralization was greater under IC than under PP and ST at this depth. Potential N mineralization at the soil surface decreased with increasing PP frequency. At a depth of 25 to 75 mm, no differences in potential

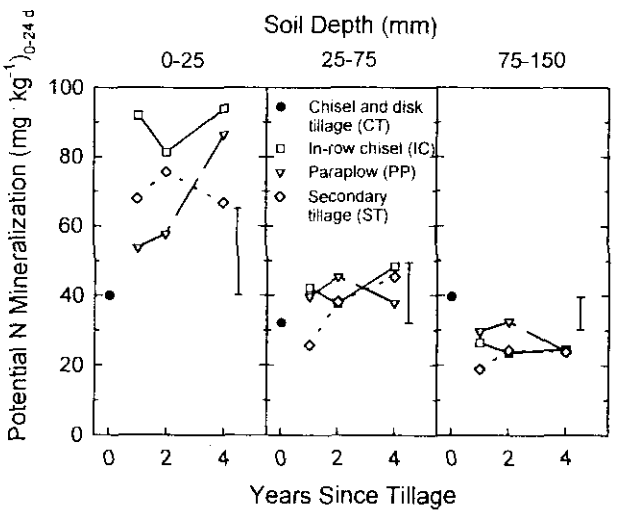

Fig. 4. Potential N mineralization as affected by soil depth, tillage type, and tillage frequency (1, 2, and 4 years since tillage were tilled 4, 2, and 1 years in four years, respectively). Error bars are LSD ($P \leq 0.01$).

N mineralization among tillage types and frequencies were observed. At a depth of 75 to 150 mm, potential N mineralization was lower under alternative tillage systems than under CT, and averaged across tillage frequencies it was greater under PP than under ST.

The ratios of mineralized C to mineralized N during 0 to 24 d of incubation were 18.8 ± 5.3 at a depth of 0 to 25 mm, 13.2 ± 2.2 at a depth of 25 to 75 mm, and 13.1 ± 1.9 at a depth of 75 to 150 mm. Ratios of mineralized C to mineralized N were similar to soil organic C to N ratios, except at the soil surface, where there were more readily mineralizable substrates that may have resulted in more immobilization of N than at lower depths.

Cotton Yield

Cotton yield from 1994 to 1996 was inconsistently affected by any of the alternative tillage types and frequencies (data not shown). Seed cotton yield under CT averaged 0.42, 0.80, and 1.54 Mg ha^{-1} in 1994, 1995, and 1996, respectively. However, seed cotton yields in alternative tillage systems in 1994, 1995, and 1996 were 0.76 ± 0.09, 0.89 ± 0.11, and 1.64 ± 0.11 Mg ha^{-1}, respectively.

Sensitivity of Soil Properties to Management

Although trends in the response of soil C and N pools and soil aggregation to tillage type and frequency were similar, sensitivity of these properties to changes in tillage management strategies was different when comparing the ratio of a soil property under alternative tillage systems with that under CT. Standing stock to a depth of 150 mm under alternative tillage types and frequencies compared with CT averaged 46% greater for basal soil respiration, 28% greater for particulate organic C, 19% greater for soil microbial biomass C, 15% greater for mean-weight diameter, 7% greater for potential N mineralization, and 2% lower for soil organic C. At a depth of 0 to 25 mm, basal soil respiration was 4-fold greater, particulate organic C was 3.3-fold greater, soil microbial biomass C was 2.1-fold greater, mean-weight diameter was 26% greater, potential N mineralization was 88% greater, and soil organic C was 78% greater under alternative tillage types and frequencies than under CT. Similarly, soil microbial biomass C was more sensitive to changes in residue inputs (Powlson et al., 1987) and basal soil respiration was more sensitive to tillage management (Franzluebbers and Arshad, 1996a) than was soil organic C. Despite the overall importance of total soil organic C and N to numerous soil functions, measurement of the intermediate (particulate organic C and N) and active (soil microbial biomass C, basal soil respiration, and potential N mineralization) pools of organic matter may provide a more sensitive approach to assess soil quality, especially in locations where soil organic matter, nutrient cycling, and water infiltration and retention are important.

SUMMARY AND CONCLUSIONS

In general, soil C and N pools and aggregation were more evenly distributed in the soil under conventional chisel and disk tillage (CT), but they were concentrated near the soil surface under no-tillage planting with alternative tillage types and frequencies. We conclude that improvement in soil quality could be achieved using any of the alternative tillage systems combined with no-tillage planting. Compared to a situation with four years since the last alternative tillage event, more frequent alternative tillage reduced the potential improvement in bulk density and in soil organic C and N pools near the soil surface most with paraplow (PP), intermediate with secondary tillage (ST), and least with in-row chisel (IC) as the alternative tillage type. However, the detrimental effects of more frequent alternative tillage were not as severe as continuation of CT without cover crop. Judicious and infrequent use of IC to improve seed establishment, of PP to improve deep water percolation, and of ST to control summer season weeds (which all attempt to minimize surface residue incorporation) in combination with no tillage planting and use of a cover crop should be considered viable alternatives to CT without a cover crop (which leaves little protective cover on these highly erodible soils).

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